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NASA TECHNICAL TRANSLATION NASA TT F-15,237

REDUCTION OF AIRCRAFT NOISE IN THE VICINITY OF AIRPORTS

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(NASA-TT-F-15237) REDUCTION OF AIRCRAFT NOISE IN THE VICINITY OF AIRPORTS (Kanner (Leo) Associates) ~~39~~ 40 p HC CSCL 01C

N74-15718

Unclas

G3/02 29331

Translation of "Snizhenie shuma samoletov v okrestnostiakh aeroportov," American Institute of Aeronautics and Astronautics and Gosudarstvennyi Komitet po Nauke i Tekhnike, USSR/US Aeronautical Technology Symposium, Moscow, USSR, July 23-27, 1973, Paper, 30 pp.

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
WASHINGTON, D.C. 20546 FEBRUARY 1974

STANDARD TITLE PAGE

1. Report No. NASA TT F-15,237	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle REDUCTION OF AIRCRAFT NOISE IN THE VICINITY OF AIRPORTS		5. Report Date February 1974
		6. Performing Organization Code
7. Author(s) B.N. Mel'nikov		8. Performing Organization Report No.
		10. Work Unit No.
9. Performing Organization Name and Address Leo Kanner Associates, P.O. Box 5187, Redwood City, California 94063		11. Contract or Grant No. NASw-2481
		13. Type of Report and Period Covered Translation
12. Sponsoring Agency Name and Address NATIONAL AERONAUTICS AND SPACE ADMINISTRATION, WASHINGTON, D.C. 20546		14. Sponsoring Agency Code

15. Supplementary Notes

Translation of "Snizhenie shuma samoletov v okrestnostiakh aeroportov," American Institute of Aeronautics and Astronautics and Gosudarstvennyi Komitet po Nauke i Tekhnike, USSR/US Aeronautical Technology Symposium, Moscow, USSR, July 23-27, 1973, Paper, 30 pp.

16. Abstract

The main sources of noise from modern transport aircraft are examined along with currently employed means of minimizing the influence of aircraft noise on communities neighboring air terminal areas. The complexity of the task is elucidated by stressing the importance of unified development and implementation of measures designed to reduce the noise both at the source and along its path of propagation. These measures are identified as specially designed low-noise engines, traffic control and flight maneuver procedures stressing noise abatement, and architectural as well as urban planning guidelines in the growth of nearby communities. Operational examples of noise abatement procedures employed by current Soviet transport aircraft are described, and their effectiveness is evaluated.

17. Key Words (Selected by Author(s))	18. Distribution Statement Unclassified - Unlimited		
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages	22. Price

NASA-HQ

Annotation

The principal sources of noise of modern transport aircraft and the use of methods of reduction of the action of noise on the population living in the vicinity of airports are examined. It is emphasized that only multiple development and introduction of measures, providing for a reduction in noise at the source and on its propagation path, for example, by means of building less noisy aircraft engines, use of special flight maneuver procedures and air traffic control as well as design-planning measures, permit successful solution of this problem.

Operating noise reduction procedures and their effectiveness for domestic passenger jet engine aircraft are examined in the paper, and ways are pointed out to decrease noise created during letdown of an aircraft for landing. Singularities of the noise characteristics of the supersonic Tu-144 aircraft and applicable methods for reducing its intensity are indicated.

The basic conditions of standard requirements, applicable in the USSR, on limitation of building in the vicinity of airports from conditions of the noise created by aircraft are reported.

REDUCTION OF AIRCRAFT NOISE IN THE VICINITY OF AIRPORTS

B.N. Mel'nikov

In the last 10-15 years, in a number of countries with developed aircraft industries, extensive studies have been carried out on the characteristics of jet engine aircraft noise and the singularities of generation and action of noise on the population, for the purpose of developing effective measures to reduce it. /3*

The noise reduction problem is extremely complicated, and only a multiple development and systematic introduction of measures providing for noise reduction at the source and on its propagation path, for example, by means of building quieter aircraft, the use of special flying procedures, design-planning measures and special procedures for air traffic control, permit solution of this problem. We dwell only on methods of reduction of irritating noises, by means of use of operational procedures and limitations on building in the vicinity of airports.

These methods, together with the introduction of quieter aircraft with double flow turbojet engines (DTJE), are quite widely used in the Soviet Union. In developing and introducing them, the experience of other countries and, in particular, the recommendations of the International Civil Aviation Organization (ICAO) and the International Organization on Standardization (ISO) have been studied.

Operational procedures for aircraft noise reduction are, generally speaking, forced measures, which complicate aircraft

*Numbers in the margins indicate pagination in the foreign text.

operation as a rule and, sometimes, reduce the flight safety level. However, the harmful effect of noise in the vicinity of modern airports is being reached with the continually increasing rate of flights of such significance, that the stream of complaints and protests from the population living in these areas forces urgent measures to be taken.

At the same time, efforts to reduce the noise of operating aircraft, by means of design improvements, are expensive and usually are connected with deterioration of the flight characteristics of the aircraft and of its economy [1]. Therefore, for the purpose of reducing the acuteness of the problem, even with the recent introduction of new, comparatively quiet aircraft, satisfying the ICAO standards [2] and the similar domestic standard [3], quite extensive use of operational procedures and design-planning measures is foreseen.

Selection of Optimum Control of Aircraft During Takeoff with Decreased Noise

The problem of developing special methods of aircraft piloting during takeoff admits of mathematical modeling, and it can be solved by the methods of optimum control theory [4]. /4

We will describe the movement of the center of mass of an aircraft by a system of differential equations

$$\frac{dx}{dt} = f(x, u),$$

where

$$x = (x_1, x_2, \ldots, x_5)$$

$$f = (f_1, f_2, \ldots, f_5) \quad \text{is a vector function;}$$

$$u = (u_1, u_2, \ldots, u_6) \quad \text{is a control function;}$$

$x_1 = v$ is the flight speed; $x_2 = \theta$ is the angle of inclination of the flight path to the horizon; $x_3 = \psi_c$ is the deflection angle of the flight path; $x_4 = l$ and $x_5 = h$ are the current coordinates; $u_1 = \alpha$ is the angle of attack; $u_2 = \beta$ is the slip angle; $u_3 = \gamma_c$ is the high-speed bank angle; $u_4 = \phi$ is the deflection angle of the thrust vector; $u_5 = \delta_3$ is the deflection angle of the mechanization elements; $u_6 = P$ is the engine thrust.

$$
\begin{aligned}
f_1 &= \frac{P}{m}\cos(\alpha-\varphi)\cos\beta - \frac{X}{m}\sin\beta + \frac{Z}{m}\sin\beta - g\sin\theta;\\
f_2 &= \frac{P}{mv}\left[\sin(\alpha-\varphi)\cos\gamma_c + \cos(\alpha-\varphi)\sin\gamma_c\sin\beta\right] -\\
&\quad - \frac{X}{mv}\sin\beta\sin\gamma_c + \frac{Y}{mv}\cos\gamma_c - \frac{Z}{mv}\cos\beta\cdot\cos\gamma_c - \frac{g}{v}\cos\theta;\\
f_3 &= \frac{P}{mv\cos\theta}\left[\sin(\alpha-\varphi)\sin\gamma_c - \cos(\alpha-\varphi)\sin\beta\cdot\cos\gamma_c\right] -\\
&\quad - \frac{X}{mv\cos\theta}\sin\beta\cdot\cos\gamma_c - \frac{Y}{mv\cos\theta}\sin\gamma_c - \frac{Z}{mv\cos\theta}\cos\beta\cdot\cos\gamma_c;\\
f_4 &= v\cos\theta; \qquad f_5 = v\sin\theta,
\end{aligned}
$$

where X, Y, and Z are aerodynamic forces and m is the aircraft mass.

For modern jet aircraft, the total radiated acoustical power W can be presented in the form of the sum of acoustical powers radiated by the jet stream and the compressor.

The action of noise on the population usually is determined by the acoustical pressure level, the spectral composition and duration of action of the noise. For an estimate of the irritating action of noise during a single aircraft flight, the EPNL effective perception of noise level system usually is used. Taking account of a number of simplifying assumptions, in accordance with this criterion, the following value can serve as a measure of the irritating effect of noise:

$$A = a\int_0^T \frac{\Phi(t)}{R^2}\,dt = a\int_0^T 10^{L/10}\,dt,$$

where a is a constant, Φ is the noise directionality characteristic, R is the distance from the aircraft to the noise measurement point and L is the acoustical pressure level at the control point. /5

Thus, the problem of finding the optimum flight program is reduced to determination of that solution of the system of equations of motion which provides the minimum integral criterion A. A singularity of this problem is limitation by phase coordinates, control functions and maximum noise level. The problem can be generalized for the case of minimization of noise in a section of an area with fixed boundaries.

For solution of this problem, it is recommended that the method of fastest descent be used, permitting the optimum noise flight conditions to be investigated by means of computer. As a result, the most advantageous aircraft control program as to noise is determined, with allowance for the assigned limitations.

This method was used in determination of optimum takeoff flight paths of a number of subsonic aircraft. As the calculations showed, in accomplishing optimum control by a number of parameters, the aircraft noise level can be reduced to a value of down to 1-12 PNdB.

The proposed algorithm can be used for both determination of the most advantageous takeoff flight paths of prospective aircraft, including SST, and in solution of problems of increasing effectiveness of takeoff methods for operating aircraft.

Operating Aircraft Noise Reduction Procedures

The selection of special operating procedures depends on local conditions, mainly on the location of populated points near airports, aircraft types and their operating conditions.

The most effective is the use of a course excluding low-altitude flyovers of populated points, while observing regulated flight safety conditions. Operating procedures, directed towards noise reduction during aircraft takeoff, as is well-known, include:

1. initial climb with a considerable gradient to provide the greatest altitude during approach to a populated place;
2. reduction in the engine operating modes during flyover of populated points;
3. execution of turns in the direction away from populated points;
4. use of the preferable runway noise conditions;
5. use of the minimum noise course.

In all cases, with the exception of the second, a reduction /6 in the irritating action of noise is achieved, as a result of increasing the distance between the noise source and populated points or of reduction in flyovers of them; in the case of engine throttling, by means of decrease in radiation by the source. This procedure is most effective for single-flow jet engines and double-flow turbojet engines with a low degree of double flow, in which the decisive noise source is the jet flow.

Increase in Gradient of Initial Climb

Flight with negligible acceleration after liftoff and holding constant the speed reached in the subsequent climb (usually, this is achieved in practice at a speed of at least V_2 + 20 km/h, where V_2 is the safe takeoff speed) provides approximately twice the initial climb angle of continuous aircraft acceleration. As a result of this, under otherwise equal conditions, the noise is reduced by 6 dB on the average. During a takeoff by this method, a redistribution of the balance of the available thrust takes place: the major part of it is expended in creation of vertical velocity V_y. In a normal takeoff with continuous acceleration, used previously, for example, in operation of the two-engine types Tu-104 and Tu-124 aircraft, a thrust, equal to the thrust of approximately one engine, is expended in creation of accelerated motion of the aircraft and the same thrust on overcoming drag and only a small part of it (about 0.1 of the thrust of one engine) in creation of V_y [5].

The noise created in an area during takeoff of an aircraft of this type is determined by two main factors, distance from the aircraft and the operating modes of its engines. The flight altitude of an aircraft at a given distance from the start of the run and, consequently, the noise created by it, depends on six independent variables: engine thrust, aircraft weight, its wing area, a coefficient allowing for the effect of induced drag, the drag coefficient at zero lift and flight speed [6].

On the basis of analysis of the known relationships and results of flight research, it has been established that the climb gradient, aside from other factors, depends on the deflection angle of the flaps. Therefore, at the flight altitude of a control point, located at a specific distance from the start of the run, it can be increased, as a result of selection of the optimum flap deflection angle during takeoff.

For preservation of a definite degree of flight safety, flap deflection leads to an increase in run length during takeoff and the initial climb angle. An increase in the flap deflection /7
angle decreases the run length; however, in this case, the initial climb angle decreases. However, as experience shows,

in the near and distant zones (up to 4.5 km and over 8 km from the start of the run, respectively), a reduction in noise by means of choice of the optimum flap position during takeoff is low, reaching 2 TPNdB.

Sometimes, for reduction in the standard noise levels, the takeoff weight of the aircraft has to be reduced. The noise reduction in this case is achieved by means of decrease in the run length, increase in the initial climb angle and a relatively large reduction in the engine operating mode for maintenance of a given climb gradient. Reduction in takeoff noise by means of reduction in the useful load is economically disadvantageous.

Engine Throttling

Engine throttling is carried out for the purpose of reduction in noise during approach to a populated place after gaining altitude with the maximum gradient. The minimum altitude for throttling back is 200 m, and the minimum mode is selected in such a way that, with a maximum takeoff weight and initial temperature of +15°C, the positive climb gradient is at least 5%, in accordance with standards [3].

The results of use and acoustical effectiveness of this method are quite diverse. With significant decrease in noise under the takeoff flight path in the engine throttle-back section, increase in it is possible in regions located beyond this section on the takeoff course. A decrease in noise, achieved as a result of throttling back the engines, depends significantly on engine type. Overall, this reduction is greater for jet engines than for double-flow turbojet engines, and it can be expressed by the approximate ratio $\Delta PNL = 50 \log P/P_M$ for jet exhaust noise; in the case when the noise of a double-flow turbojet engine compressor is decisive, the reduction amounts to only $25\log P/P_m$, where P is the engine thrust in the throttled mode and P_m is the maximum thrust.

Execution of Climbing Turns

Execution of climbing turns permits noise in populated points, located close to an airport along the takeoff course, to be reduced significantly. This is one of the main methods used in selection of the minimum noise course. Turns are accomplished after reaching an altitude of at least 150 m above the ground and obstacles under the flight path, at a bank angle of not over 15°. Turns usually are not permitted in combination with throttling back the engines.

Use of Runways Preferred as to Noise

It is used more often at airports with several runways, separate ones of which do not have populated areas located close to the direction of the axis, and, in the case of some runways, of populated points to one side. This procedure for reduction of the irritating action of noise is not used, if the runway is /8
covered with snow, slush, a layer of ice, water, mud, oil, as well as with cross and tail components of the wind exceeding 7.5 and 2.5 m/sec, respectively.

Use of Minimum Noise Course

In a number of cases (depending on the location of populated points in the vicinities of airports), it permits the irritating action of noise to be reduced considerably or even completely eliminated. Limited possibilities of use of this method frequently are determined by deterioration in economy of operation, in connection with reduction in the airport throughput capacity and complications in air traffic control.

Let us briefly examine the results of flight tests, carried out with all types of civil aviation aircraft, for the purpose of working out methods of flying with a decrease in noise in the area during takeoff.

In the Tu-104 turbojet aircraft, the first in the world to begin regular passenger flights, such investigations were begun comparatively long ago [7, 8], and the method of piloting an aircraft with decreased noise during takeoff is given in works [9, 10].

The results of investigation of the noise characteristics and the method of flying the Tu-124 aircraft with decreased noise over an area was examined in works [5, 9, 10, 11].

As an example, let us examine more in detail the method of flying modern aircraft of the Il-62 and Tu-134 types.

Decrease in Noise During Takeoff of Il-62 Aircraft

It is achieved as a result of use of the following flying method [12].

Selection of flap position, run, liftoff and landing gear retraction of the aircraft is made in accordance with the recommendations of the effective Flight Operations Handbook. In the process of landing gear retraction, the aircraft accelerates to a speed of 320-340 km/h, depending on takeoff weight.

Takeoff weight, t	130 and less	140	160
Instrument speed, km/h	320	330	340

In the process of subsequent acceleration of the aircraft to a speed of 350 km/h, for takeoff weights up to 150 t inclusive, and to 360 km/h, for weights of 150-160 t, retraction of the flaps from 30° to 15° begins at an altitude of 120 m.

During daytime takeoff and in the event the distance of a populated place is over 6.5 km from the start of the run, the engine operating mode is changed to the rated one at an altitude of 400 m. Maintaining the speed constant at 350-360 km/h and the flaps extended to 15°, a climb to 800 m is accomplished, /9
after which the aircraft is changed to the mode of acceleration to the speed of the established c l i m b. During acceleration to a speed of not over 400 km/h, the flaps are retracted completely.

In a night takeoff or in the direction of populated places, located at a distance of less than 6.5 km from the start of the run, as well as during departure from airports with established noise limitations, the expected maximum noise level must be determined from the graphs presented in Figs. 1 and 2, as well as, in case of necessity, exact determination for the specific altitude conditions for use of engine operating modes and modes guaranteeing permissible noise levels.

For noise reduction, a decrease in mode to 80% of IP-33 is permitted, after completion of flap retraction to 15° and at an altitude of at least 150 m. With populated points located very close, the engine operating modes must be reduced to the required values at an altitude of at least 150 m, after which retraction of the flaps from 30° to 15° is permitted, with maintenance of the speed at 350-360 km/h. In all cases, the aircraft must continue to climb with a climbing speed of at least 4.0 m/sec.

The height for change in engine operating modes and modes ensuring a noise level close to the permissible one, is determined from the initial data, including the actual takeoff weight of the aircraft, air and ground temperature, wind velocity component along the runway and distance of a populated point from the start of the run.

The combined effect of the first three parameters is taken into account through the arbitrary concept of "corrected weight," determined by means of the graph presented in Fig. 1.

An example of a calculation is shown in the graphs presented (Figs. 1 and 2) by dashed lines with arrows, for the following conditions:

aircraft takeoff weight	160 t
air temperature	+35°C
headwind component	2.5 m/sec
atmospheric pressure	730 mmHg
distance of populated point from start of run	6.0 km

For these conditions, the corrected weight equals approximately 167 t. To provide the levels adopted as permissible, for example, 102 PNdB, a decrease in the engine operating mode to 80% must be carried out at an altitude of 350 m, continuing the climb at a constant speed of 360 km/h. After flying over the populated point or gaining an altitude of 300 m, the engine is changed to the rated mode, and, in the process of acceleration of the aircraft, at a speed of not over 400 km/h, the flaps are retracted.

Noise Reduction During Takeoff of Tu-134 Aircraft /10

The choice of flap position, takeoff run, liftoff and landing gear retraction is made in accordance with the recommendations of the Flight Operations and Aircraft Piloting Handbook. After liftoff, in the process of landing gear retraction, the aircraft accelerates without delay to an instrument speed of 280-290 km/h, for flap deflections of 20° and 300 km/h for flaps deflected by 10°. Subsequent gain of an altitude of 800 m is carried out at a constant speed of 280-300 km/h, depending on the flap deflection angle, for all takeoff weights up to 45 t inclusive.

During daytime takeoff and in the event the distance of a populated place exceeds 6 km from the start of the run, the engine operating mode must be changed from takeoff to rated at an altitude of 400 m. At an altitude of 800 m, the stabilizers are reset to the zero position, and the aircraft is accelerated to the speed recommended in the Handbook. During acceleration, the flaps are retracted at a speed of 330 km/h.

During night takeoff, as well as in the direction of populated places located at a distance of less than 6 km, and during departure from airports, at which noise limitations are established, the expected noise levels must be determined from the annexed graphs (Figs. 3 and 4) and, in case of necessity, the altitude for change of the engine operating modes and the modes providing permissible noise levels must be precisely defined for the conditions given (takeoff weight, meteorological conditions and location of populated points).

In these cases, a reduction to not less than 88% is permitted, after completing landing gear retraction, at an altitude of at least 150 m. In all cases, the aircraft must continue to gain altitude with a climbing speed of at least 2.5 m/sec.

An example of calculation of the altitude for change in engine operating modes and modes providing noise levels close to those permissible is shown in the graphs presented by dashed lines with arrows, for the following conditions:

aircraft takeoff weight	44 t
air temperature	+30°C
headwind component	5 m/sec
atmospheric pressure	730 mmHg
distance of boundary of populated point from start of run	4 km

In this case, the corrected weight is close to 50 t. To provide the noise level accepted as permissible for daytime and a given airport, for example, 102 PNdB, a change in engine operating mode to n = 88% must be carried out at an altitude of approximately 200 m, continuing to climb at a speed of 280-290 km/h. After passing over the populated point or reaching an altitude of 800 m, the engines are changed to the rated mode of operation, and the flaps are retracted during acceleration of the aircraft, at an instrument speed of 330 km/h. /11

Characteristics and Comparative Estimates of Effectiveness of Flying Methods Used

The basic elements, comparative characteristics and acoustical effectiveness of the methods of flying domestic aircraft with the least noise in an area during takeoff are shown in Table 1.

TABLE 1.

Basic Characteristics	Aircraft Type Tu-104	Tu-124	Tu-134	Il-62
1	2	3	4	5
Number and type of engines	2 TJE*	2 DTJE*	2 DTJE*	4 DTJE*
Maximum takeoff weight, t	76	38	45	160
Flap position during takeoff, degrees	10	10/20	10/20	30

[Table continued on following page.]

*[TJE - turbojet engine; DTJE - double-flow turbojet engine.]

Table 1, continued.

1	2	3	4	5
Initial climbing speed, km/h	350	300/270	300/280	380
Acceleration start altitude with intermediate flap setting, m	-	-	-	120
Flap position after intermediate setting, degrees	-	-	-	15
Flight speed with flaps deflected to intermediate position, km/h	-	-	-	345
Standard altitude for change in engine flight mode from takeoff to rated, m	200	300	400	400
Acceleration start and flap retraction to $\delta_A = 0°$, altitude, m	500	500	800	800
Noise level regulated by ICAO standard at control point, located at distance of 6.5 km from start of run, LPNdB	99	94	95	104
Altitude above control point 6.5 km during takeoff with maintenance of maximum engine operating mode, m	350	480	640	440
Noise level at control point 6.5 km during engine operation in maximum mode, EPNdB	118	109	110	109
Throttled mode of engine operation according to regular instruments	n = 4100 rpm	n = 88%	n = 88-90%	80% of IP-33
Noise level at control point 6.5 km during engine operation in throttled mode, EPNdB	108	102	96	103

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[Table continued on following page.]

Table 1, continued.

1	2	3	4	5
Noise reduction by means of engine throttling, EPNdB	10	7	14	6
Minimum engine throttling altitude, m	150	150	150	150
Minimum altitude of turn for purpose of noise reduction, m	200	100	100	200
Minimum turn radius at bank angle 15°, km	3.6	2.6	2.6	3.6

It should be noted that a speed, equal to V_2 + 20-30 km/h has been selected as the characteristic climbing speed for domestic aircraft. For small aircraft of the Tu-124 and Tu-134 types, this speed, selected for maximum takeoff weight, for the purpose of simplifying flying, also is used during takeoff with the lowest takeoff weights. With negligible deterioration of the acoustical effectiveness, this permits reduction in the pitch angle, which can increase considerably with increase in thrust-weight ratio, which hampers survey of the forward hemisphere and can cause the passengers discomfort. It is considered that, for the majority of types of aircraft, the pitch angle should not exceed 15°. Gaining altitude without retracting the /13 flaps (deflected to the takeoff position) also permits the pitch angle to be decreased.

Reduction in Aircraft Landing Noise

In the light of existing restrictions, this is one of the major tasks of modern aircraft construction and operating organizations. This problem has turned out to be more complicated than reduction in takeoff noise, especially in modern aircraft with double-flow turbojet engines with a high degree of double flow.

As is well-known, in letdown of an aircraft for landing, compressor (fan) noise is decisive. Depending on the gas-dynamic and design parameters of the power plant, the noise of the turbines and jetstream is heard in a number of cases. The noise also depends essentially on the engine operating mode during aircraft letdown, i.e., on its L/D ratio and number of engines.

Introduction of the well-known method of aircraft letdown along a double-beam glide path, with realization of a slope angle on the order of 6° in the outer portion, although it leads to significant reduction in noise, involves definite difficulties.

In this connection, the method of reduction of landing noise, as a result of decrease in the flap deflection angle delay in start of landing gear lowering and full flap deflection in the landing position, is more promising. As is well-known, this method, in combination with an increase in the altitude of entry into the glide path and its slope angle in a specific section, leads to a noise reduction by an amount of more than 15 EPNdB [13].

As is well-known, in accordance with standards [2, 3], the noise created by an aircraft in an area is regulated at three control points, characterizing the principal flight stages, takeoff, climb and landing letdown, located at distances of 650 m to the side of the runway axis at the point of occurrence of the maximum noise, 6.5 km from the start of the run and 2 km from the landing end of the runway along its axis, respectively. The permissible noise level depends on the aircraft takeoff weight. A diagram of the location of noise measurement points and standard noise levels, in conformance with the requirements of the standard [3], are shown in Fig. 5. A comparison of the noise levels, regulated by the ICAO standard at specific points, with the actual noise levels created by aircraft of different types, is shown in Fig. 6, from which, in particular, a significant excess over standard levels in the aircraft letdown stage is evident. The characteristics of the noise created by domestic civil aviation aircraft are presented in Table 2 [1].

Noise Reduction in Tu-144 SST [1, 14] /15

In connection with the forthcoming introduction into operation of the supersonic transport aircraft (SST), there is undoubted interest in a comparative estimate of their acoustical characteristics and use of noise reduction methods.

In designing the Tu-144, all known engineering methods for noise reduction were adopted which did not introduce appreciable impairment of the operating characteristics of the aircraft. The Tu-144 aircraft is equipped with double-flow engines, which, in the estimate of the designers, permits a noise reduction of 2-3 PNdB over that of single-flow engines of the same thrust.

As has been noted in the materials of the ICAO Committee on Aviation Noise [1, 14], the principal factor having a significant effect on the acoustical characteristics of the Tu-144 aircraft was the introduction of takeoff-landing mechanization. The decrease in noise on takeoff and landing by use of takeoff-landing mechanization is achieved by means of increase in the L/D ratio at the same lift coefficient.

An increase in the L/D ratio to 15% in the takeoff and landing modes is achieved by means of increase in curvature of the profile of the primary wing by downward deflection of the elevons. The diving moment arising during downward deflection of the elevons is compensated for by a pitching moment, created by a forward extension of the wing cross section, selection of the shape and profile of which was made so that a decrease in L-D ratio due to

TABLE 2.

Aircraft Type	Number and Maximum Thrust of Engine, kg	Maximum Takeoff Weight, kg	Maximum Landing Weight, kg	Maximum Noise Level in EPNdB			Maximum Noise Level in Conformance with Appendix 16 in EPNdB		
				During Climb	Beside Runway	During Landing Letdown	During Climb	Beside Runway	During Landing Letdown
Tu-104	2x9500	76000	68000	I08	II0	II2	98.8	I04.3	I04.3
Tu-124	2x5500	33000	35000	I02	I03	II0	93.8	I02.3	I02.3
Tu-134	2x6800	45000	40000	96	I06	I05	95.2	I02.8	I02.8
Tu-134A	2x6800	47000	43000	98	I06	I05	95.5	I03.0	I03.0
Tu-154	3x9500	90000	75000	I00	I03	I09	I00.0	I04.8	I04.8
Il-62	4xI0500	I60000	I05000	I03	I06	I09	I04.I	I06.4	I06.4
Il-62M	4xII500	I65000	I05000	I04	I06	II0	I04.5	I06.6	I06.6
Yak-40	3xI500	I6I00	I6I00	90	89	98	93.0	I02.0	I02.0

NOTE: The noise levels presented at three control points were obtained by calculation, using initial averaged band levels from the results of measurement, the method of which differs from that presented in Annex 16. Accuracy is estimated at ±3 EPNdB.

All aircraft, with the exception of the Tu-104, are equipped with double-flow turbojet engines (DTJE). Only the DTJE installed in the Il-62M and Yak-40 aircraft have a degree of double flow equal to or exceeding a value of 2.

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additional drag created by the forward wing would be significantly less than the increase in L/D ratio by downward deflection of the elevons, under conditions of ensuring t r i m. A forward wing, with a relative area of about 1.5% and a five-element curvature profile of about 30%, was used in the Tu-144 aircraft. The lift coefficient of this wing depends on the angle of attack and reaches values of 4.

The use of takeoff-landing mechanization permits the altitude above the control point to be increased by 17% during takeoff and the throttling back of the engine to be 10% greater (Fig. 7), which provides for a noise reduction of up to 6 EPNdB at this control point.

At the same time, use of takeoff-landing mechanization permits the engine to be throttled back by 15% more during landing and a total noise level reduction by 3 EPNdB to be obtained at the control point during landing. An additional decrease in compressor noise is achieved by means of use of components with long air intake channels in the Tu-144 aircraft.

By the start of passenger flights in the aircraft, jetstream noise suppressors will be installed.

A comparison of the noise levels (in EPNdB) of the SST and certain heavy subsonic aircraft, at control points regulated by Annex 16, is presented in Table 3. The Tu-144 SST noise level concerns the mass-produced aircraft, intended for passenger /16
flights, the start of which is planned for the end of 1974 - beginning of 1975. The comparison of levels presented in the table shows that the first generation SST and subsonic transport aircraft have practically identical noise.

TABLE 3.

Aircraft Type \ Flight Stage	Takeoff	Climb	Letdown	Sum of Levels at Three Control Points
	First Generation SST			
Tu-144	114	110	110	334
Concorde	111	114	115	340
	First Generation Subsonic Aircraft			
707-300C	108	114	120	342
DC8-55, 61	106	116	118	340
Convair 990A	111	120	112	343
BAC VC-10	113	110	115	338
Subsonic Aircraft Recently Introduced into Operation				
Il-62	106	103	109	318
747-100	103	112	114	329
DC-10	96	98	106	300
L-1011	95	98	103	296

Design-Planning Measures to Reduce the Effect of Noise

Measures are planned for zoning the territory in the vicinity of airports, for the purpose of limiting their development by the noise conditions, created by civil aviation aircraft. This is one of the effective methods of reduction of the irritating effect of aircraft noise.

Standards, regulating construction in the vicinity of airports by aircraft noise conditions, have been developed in the USSR. It is based on the circumstances of the results of extensive experimental research on the characteristic of noise created by civil aviation aircraft in an area, as well as by the reaction of the population to aircraft noise. The principles of measurement, estimating noise and the standard requirements of the Sanitary

Standards of Permissible Noise [15] and the corresponding recommendations of the International Standardization Organization (ISO) and ICAO, also were studied. Standards are being established for the dimensions of zones, defining the degree of suitability of territory in the vicinity of airports for residential construction on the outskirts of a city and other types of use, the method of plotting the zones and the understanding of the results obtained for the case of flight operations of various types of aircraft.

As is well-known, the irritating action of noise and the reaction of populations living in the vicinities of airports /17
depend to a significant extent on the maximum noise level, created during flyover of each aircraft, the number of flyovers, the duration of the noise action, the time of day, season, as well as the background noise level in a given region. These factors are taken into account by means of multiple criteria, indexes of the total action of noise. The equivalent noise level L_{eq} is used as such a criterion in the practice of limitation of construction in the vicinity of airports of the USSR, in the general case, defined by the ratio:

$$L_{eq} = 10 \log\left(\frac{1}{T} \sum_{ij} \tau_{ij} \cdot 10^{0,1 L_{Aij}}\right), \text{ dB A},$$

where τ_{ij} and L_{Aij} are the time of action and maximum sound level, respectively, during an overflight of an aircraft of group i on course j, and T is the total observation time.

The adopted system of standardization, besides the limitation of noise by equivalent sound level, establishes a limitation on the maximum sound level L_A, regardless of the number of overflights. Permissible values of the levels L_{eq} and L_A (in dB A) in urban residential construction territories are taken from Table 4.

TABLE 4.

Time of Day	L_{eq}	L_A
Day (from 0700 to 2300 hours)	65	90
Night (from 2300 to 0700 hours)	55	80

Depending on the size of L_{eq}, three characteristic zones are established, defining the suitability of the territory for construction in the vicinities of airports. The basic characteristics of the zones are presented in Table 5.

Civil aviation aircraft, with account taken of their operating conditions, are characterized by typical curves of equal maximum noise levels created in an area during takeoff and landing, as a result of correlation of which, all aircraft can be subdivided into separate groups, between which there is a definite interrelation, by characteristics of the noise created. However, plotting of the equal noise level curves involves definite difficulties in calculation of noise attenuation, especially at great distances from the runway. Therefore, much attention was given to correlation of known noise characteristics of domestic and foreign aircraft, for the purpose of determination of reliable relations of noise attenuation to distance, under various operating con- /18
ditions of both jet and propeller aircraft. The individual results of these studies are shown in Fig. 8.

Using the noise attenuation ratios obtained, according to known takeoff and landing flight paths for calculated conditions, as well as noise level measurements at comparatively short distances from the aircraft, characteristic relations of change in maximum sound level L_A were obtained for aircraft of the initial second group of Fig. 9.

TABLE 5.

Zone	Zone A	Zone B	Zone C
Value of L_{eq}	Day - over 70 Night - over 60	70-65 60-55	Less than 65 Less than 55
Urban residential construction	Prohibited	Permitted in individual cases with use of increased acoustical insulation	Approved
Therapeutic-prophylactic and children's institutions, schools	Prohibited	Prohibited	Not recommended close to zone boundary
Hotels	Approved with insulation of halls and bedrooms. Effectiveness of the required acoustical insulation is determined by the specific circumstances.		Approved
Administrative-public buildings	Not recommended	Approved with increased acoustical insulation	Approved
Industrial enterprises	Approved, depending on specifics of the enterprise, the question of location and noise protection is solved on the basis of the specific circumstances		

With consideration of refined data, classification of domestic civil aviation aircraft by characteristics of the noise created appear as follows (Table 6).

TABLE 6.

Group	Operating Aircraft Type	Correction to L_A Values in Fig. 9	
		Takeoff	Landing
I	Tu-104, Tu-114	+5	0
II	Tu-123, Tu-134, Il-62, Il-62M	0	
III	Il-18, An-10, An-12	-5	-5
IV	Tu-154, An-24	-10	
V	Yak-40	-15	-10

A comparison of the criterion L_{eq} with other criteria, extensively used in the practice of zoning airport vicinities in other countries, is shown in Fig. 10, using the relations presented below. It was assumed [17] that the average maximum noise level in each overflight equals PNL = 110 PNdB (or 110 EPNdB for criteria NEF and WECPNL), and that the time of action of the noise was 10 sec. /19

$$
\begin{aligned}
L_{eq} &= 10\lg 10^{0,1(PNL-13)} + 10\lg N - 37,6\ ;\\
CNR &= 10\lg 10^{0,1\,PNL} + 10\lg N - 12\ ;\\
NEF &= 10\lg 10^{0,1\,EPNL} + 10\lg N - 88\ ;\\
\mathcal{N} &= 10\lg 10^{0,1\,PNL} + 10\lg N - 30\ ;\\
NNJ &= 10\lg 10^{0,1\,PNL} + 15\lg N - 80\ ;\\
\bar{Q} &= 13,3\lg 10^{PNL/13,3} + 13,3\lg N - 52,3\ ;\\
B &= 20\lg 10^{(PNL-13)/15} + 20\lg N - 157\ ;\\
\overline{NJ} &= 10\lg 10^{0,1(PNL-13)} + 10\lg N - 39,4\ ;\\
WECPNL &= 10\lg 10^{0,1\,EPNL} + 10\lg N - 39,4\ .
\end{aligned}
$$

Among the highly fruitful ideas emerging recently in France [1, 18] is development of the concept characterized by the criterion "significant area of general annoyance," SAGA. The use of this criterion permits solution of a whole series of important problems, directly connected with reduction in the irritating action of noise of modern aircraft.

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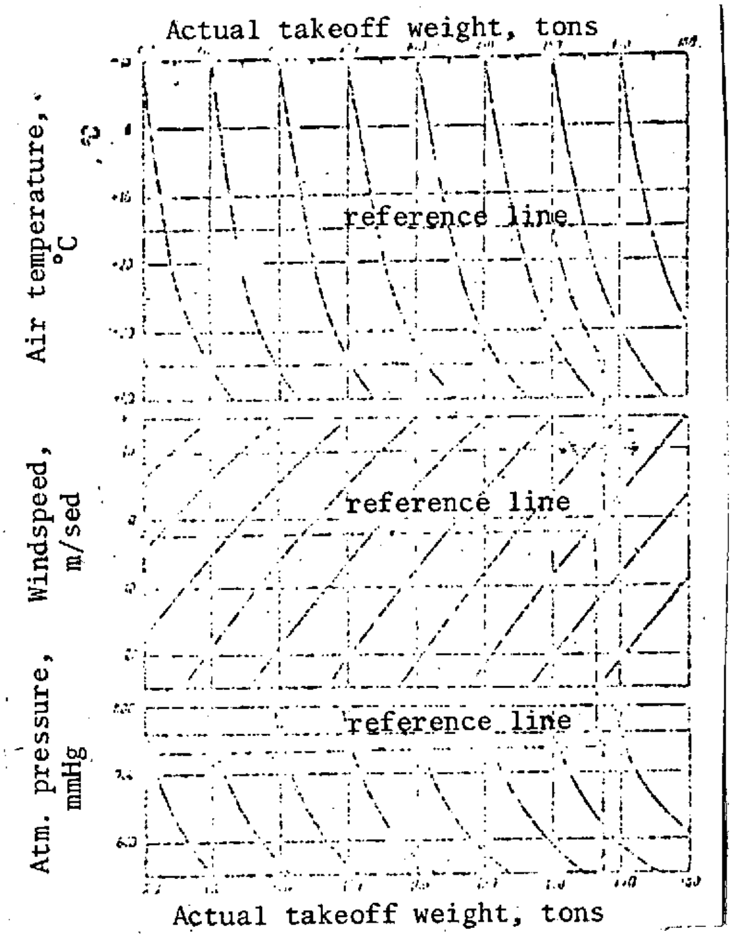
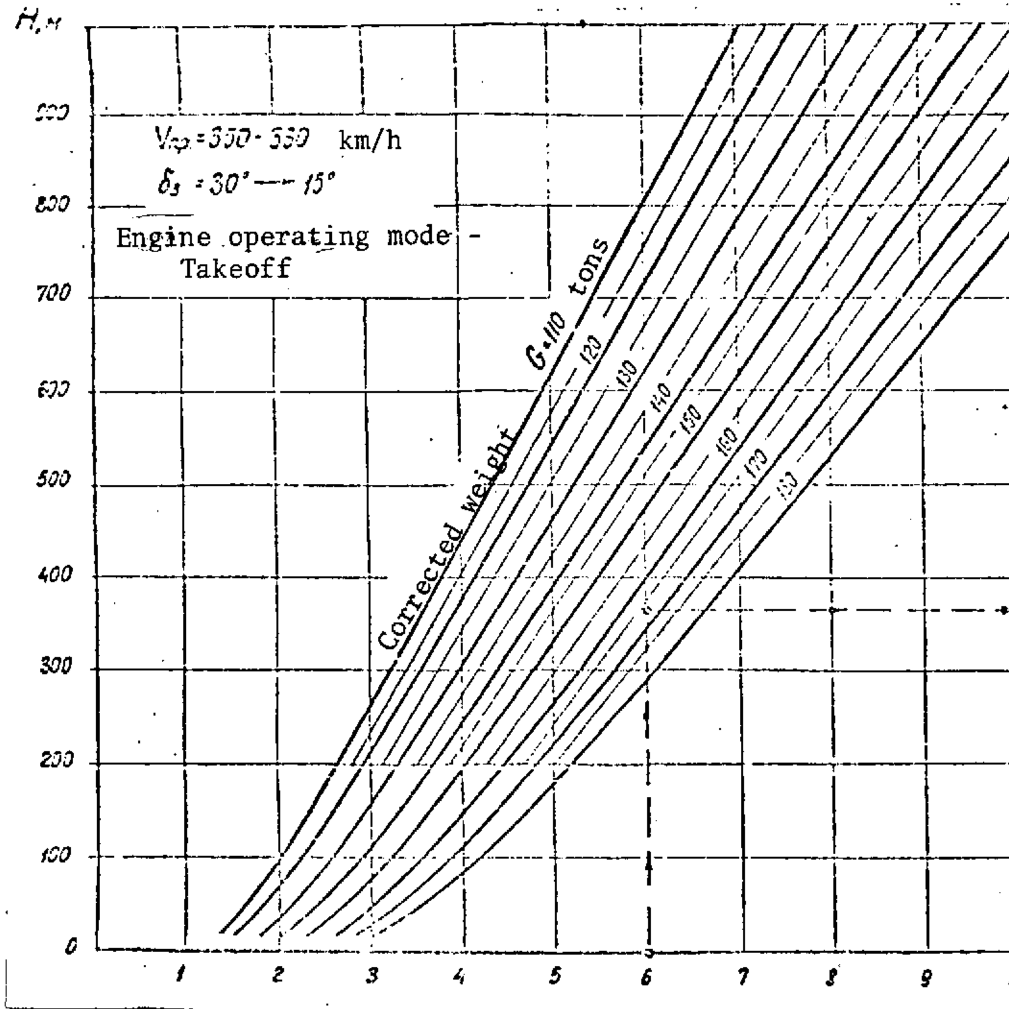


Fig. 1. Nomogram for determination of corrected weight of Il-62 aircraft.



Maximum noise created in area					
PNdB	dB(A)	EPNdB	PNdB	dB(A)	EPNdB
Flight mode			Mode 20% of IP-33		
101,0	90,0	105,0	92	81,0	97,5
102,0	91,5	105,5	93,0	81,5	93,0
103,0	91,5	106,0	94,5	83,0	99,0
104,0	92,0	106,5	95,0	84,0	100,0
105,0	93,0	107,0	97,0	85,0	101,0
106,0	94,0	107,5	97,5	85,0	101,5
107,0	95,0	108,0	99,0	87,0	102,0
108,0	95,5	109,0	100,5	88,5	102,5
109,0	97,5	110,0	102,0	90,0	104,0
111,0	99,0	111,0	103,5	91,0	105,0
112,5	101,0	112,0	105,0	93,0	105,0
115,0	102,5	113,0	107,5	94,5	107,0
117,0	105,0	115,0	110,0	95,5	108,5
120,0	107,5	117,0	113,5	99,5	110,5
124,5	112,0	118,5	117,5	103,0	113,0

Fig. 2. Flight path and noise created in an area during takeoff of Il-62 aircraft.

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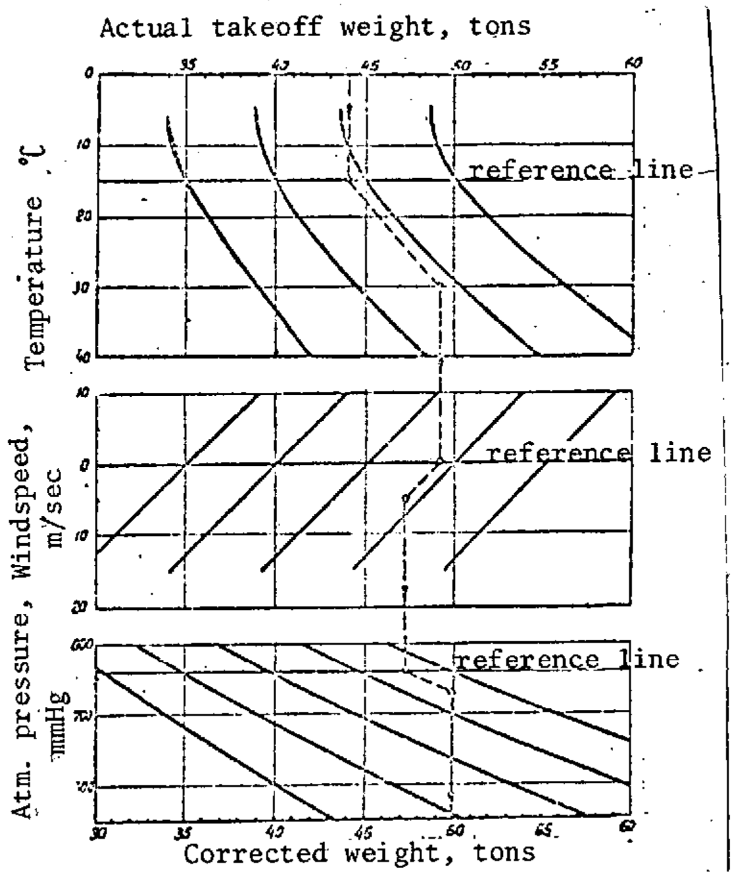

Fig. 3. Nomogram for determination of corrected weight of Tu-134 aircraft.

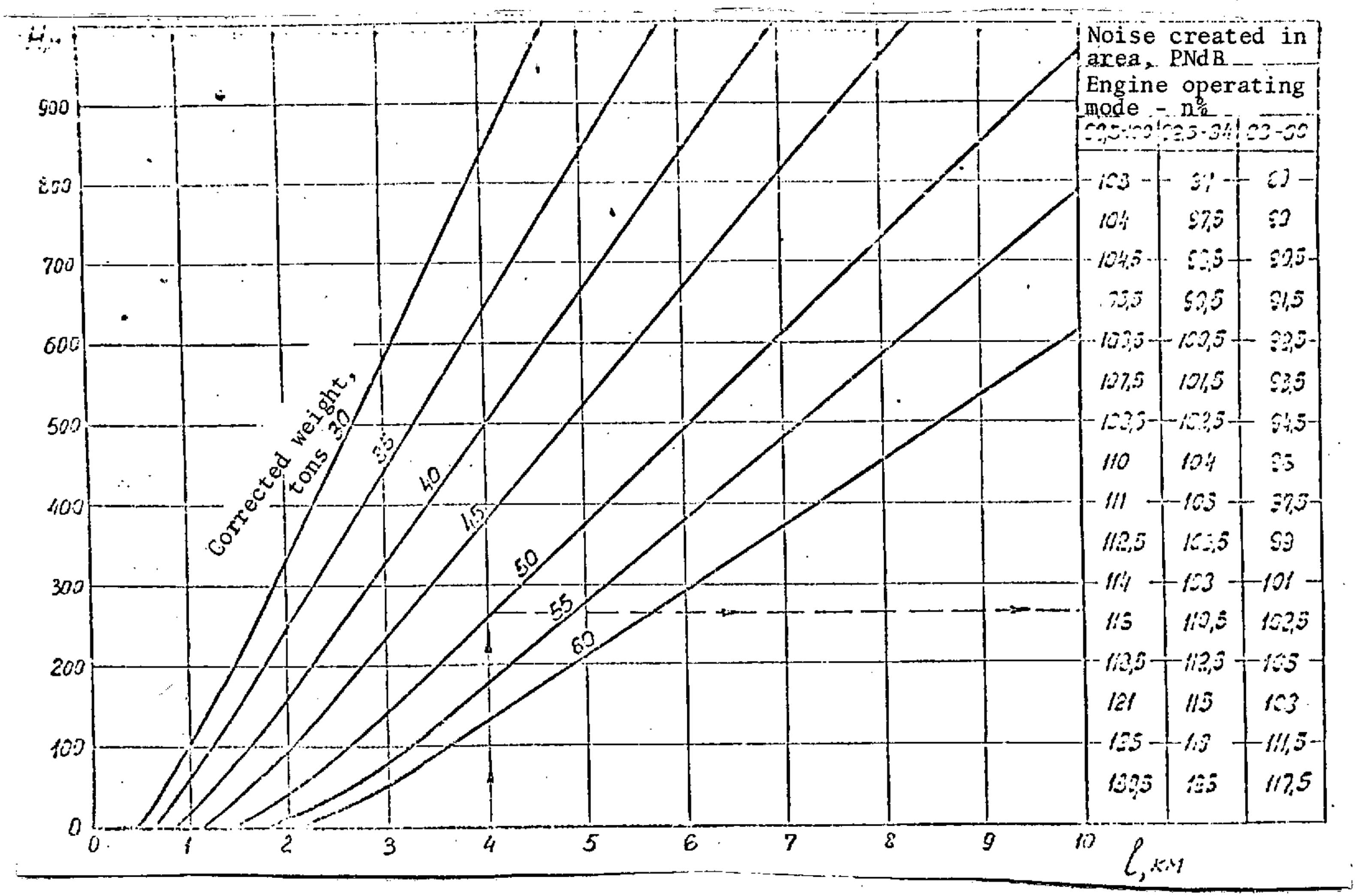

Fig. 4. Flight path and noise created in an area during takeoff of Tu-134 aircraft.

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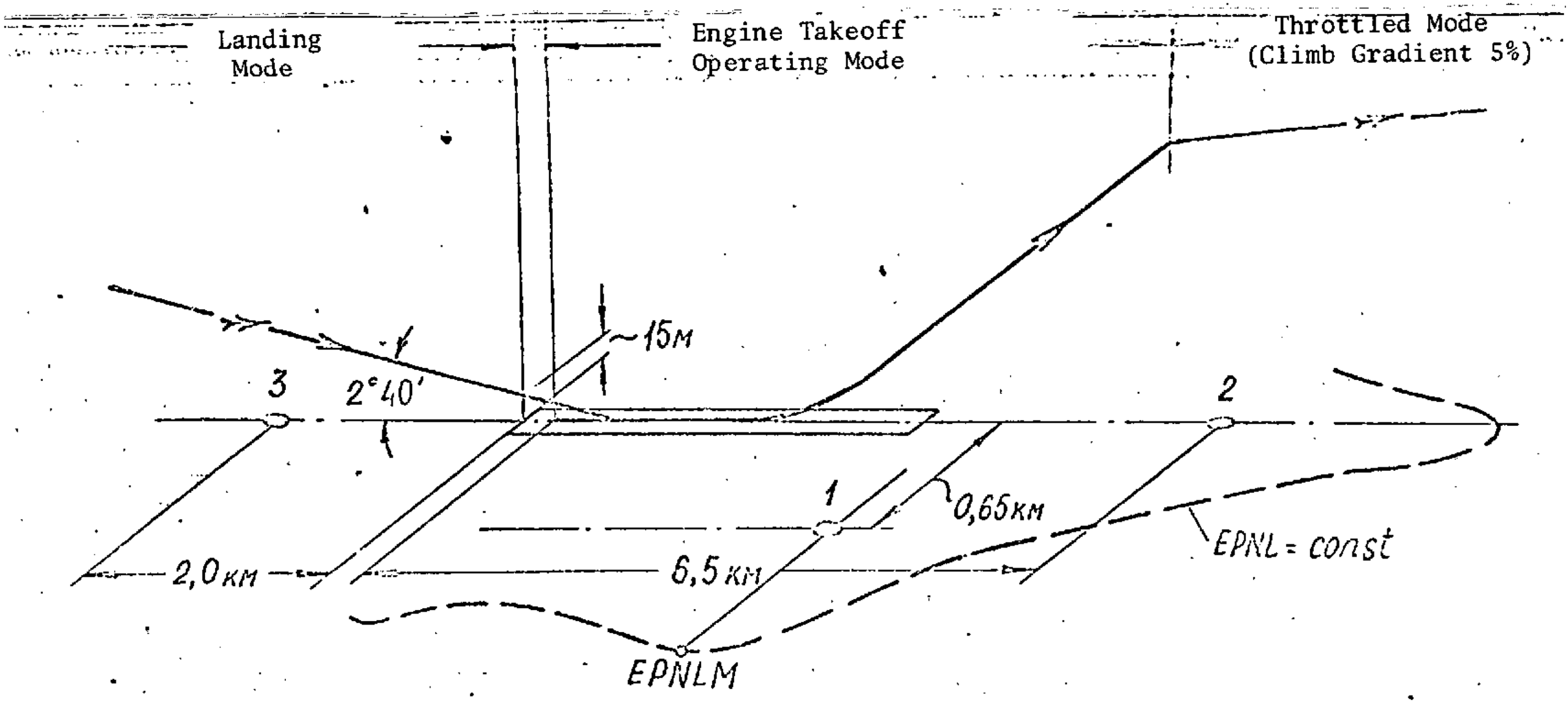

Flight Stage	Measurement Point	$G \leqslant 37{,}5$ ton	Empirical dependence of EPNL on G in weight range $37{,}5\text{ ton} \leqslant G \leqslant 200$ ton	$G \geqslant 200$ ton
Takeoff	I	I02	$6{,}6\ \lg G + 9I{,}6$	I08
Climb	2	92	$I6{,}6\ \lg G + 65{,}8$	I07
Letdown	3	I02	$6{,}6\ \lg G + 9I{,}6$	I08

Fig. 5. Diagram of location of noise measurement points and permissible noise levels regulated by GOST 17228-71[2]

[2] [GOST - All-Union State Standard.]

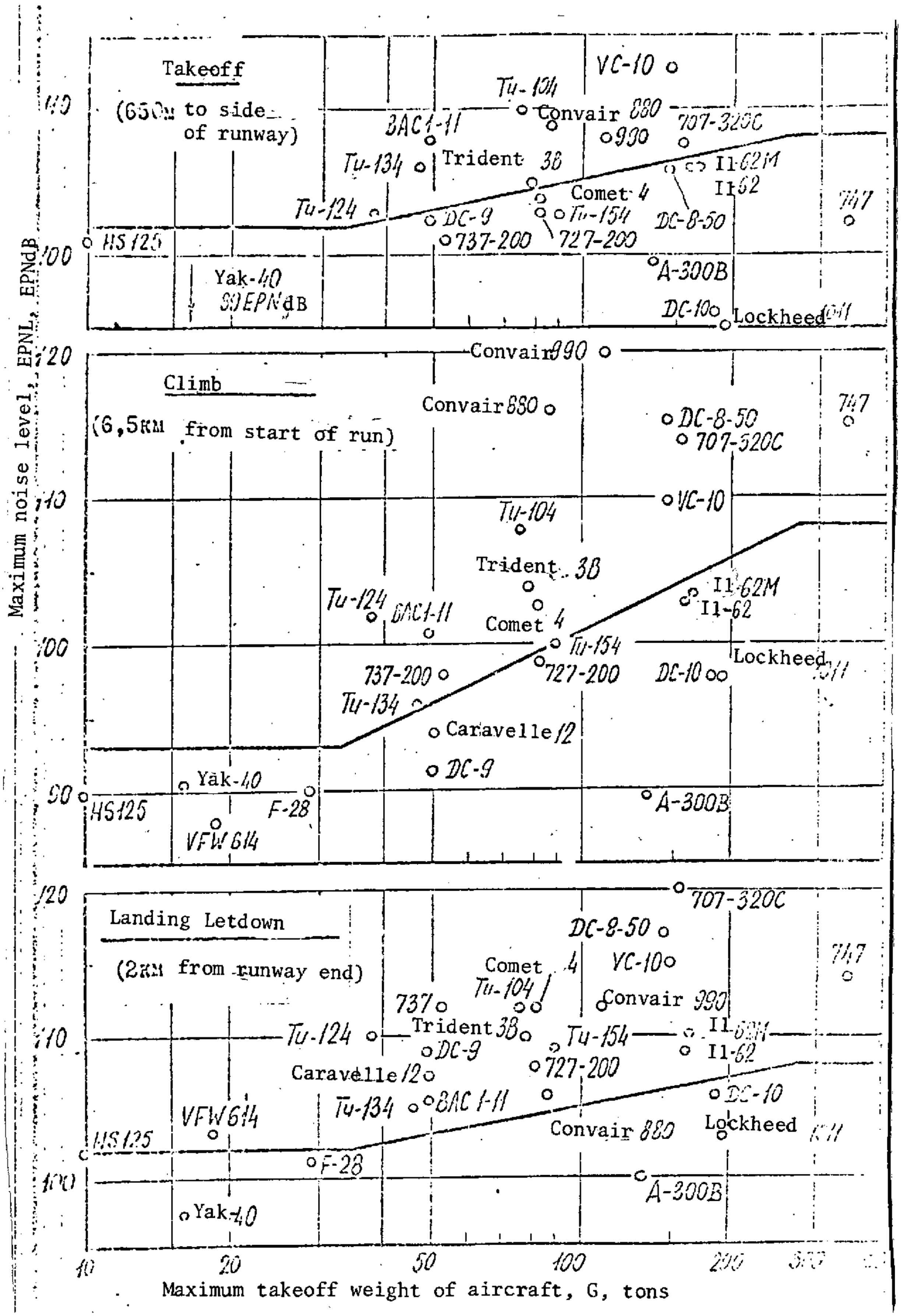

Fig. 6. Comparison of noise levels regulated at three points.

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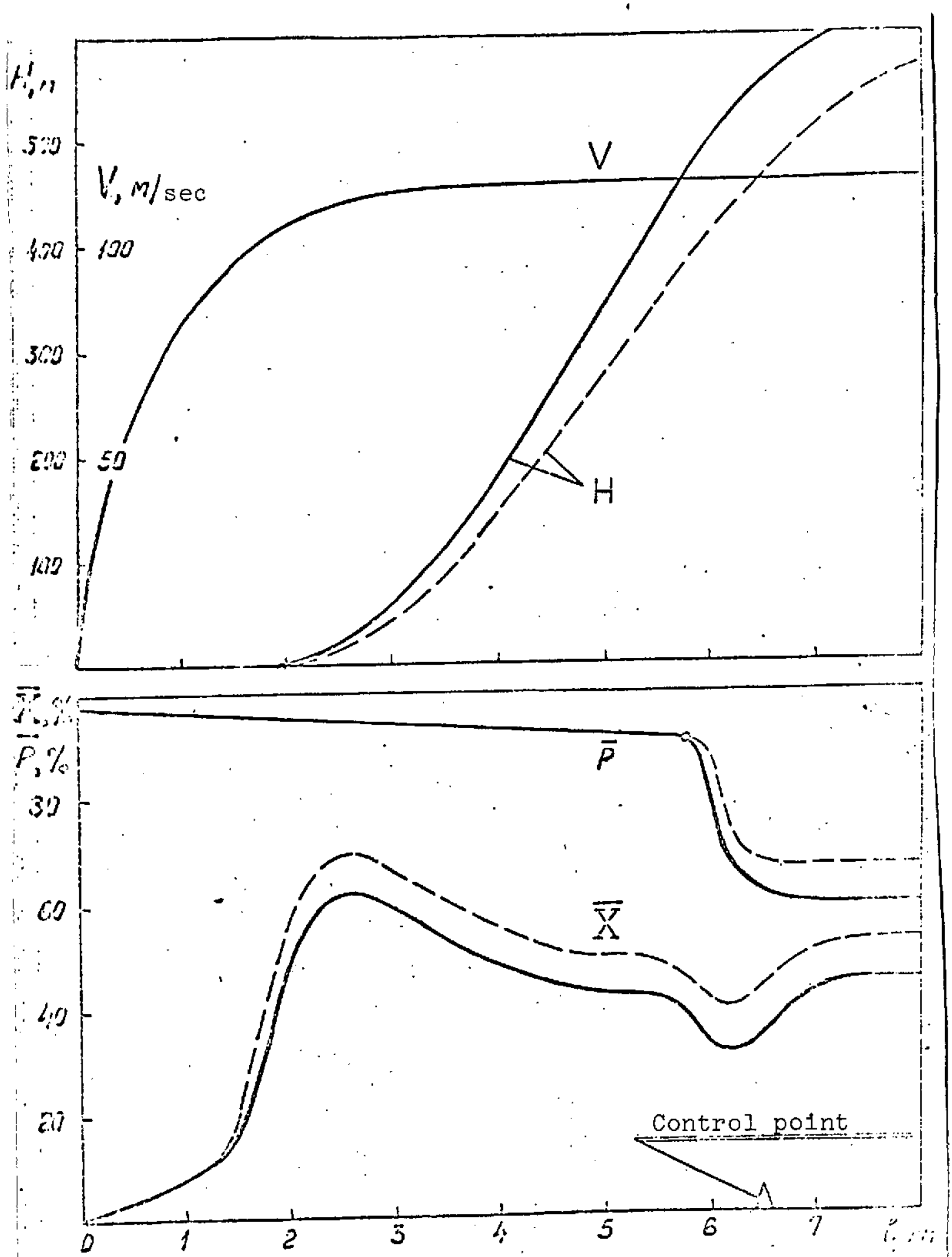

Fig. 7. Effectiveness of use of mechanization in takeoff of Tu-144 (takeoff weight 180 tons, engine throttling -- [text illegible] 5.7 km from start of run, subsequent climb with gradient of 6%).

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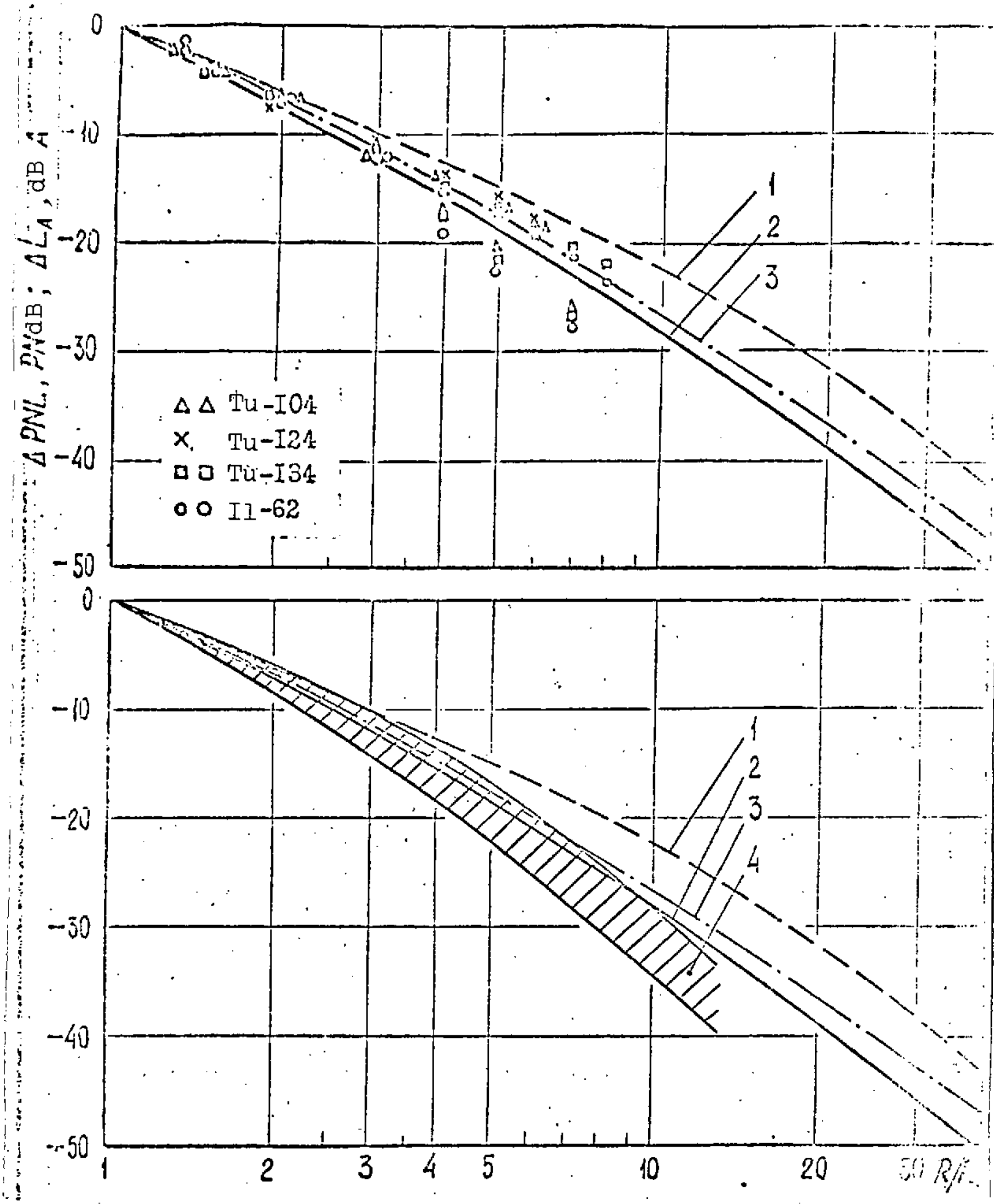

Fig. 8. Results of investigation of overflight noise attenuation with distance from aircraft takeoff: 1. Relation recommended for propeller aircraft; 2. BBN Company data; 3. recommended relation for jet aircraft; 4. region of measured levels for 707-120, DC-8, Comet 4, Caravelle 3 (from different sources); Δ × □ O from data of work [16]; Δ □ O from data of Hilscher (GDR).

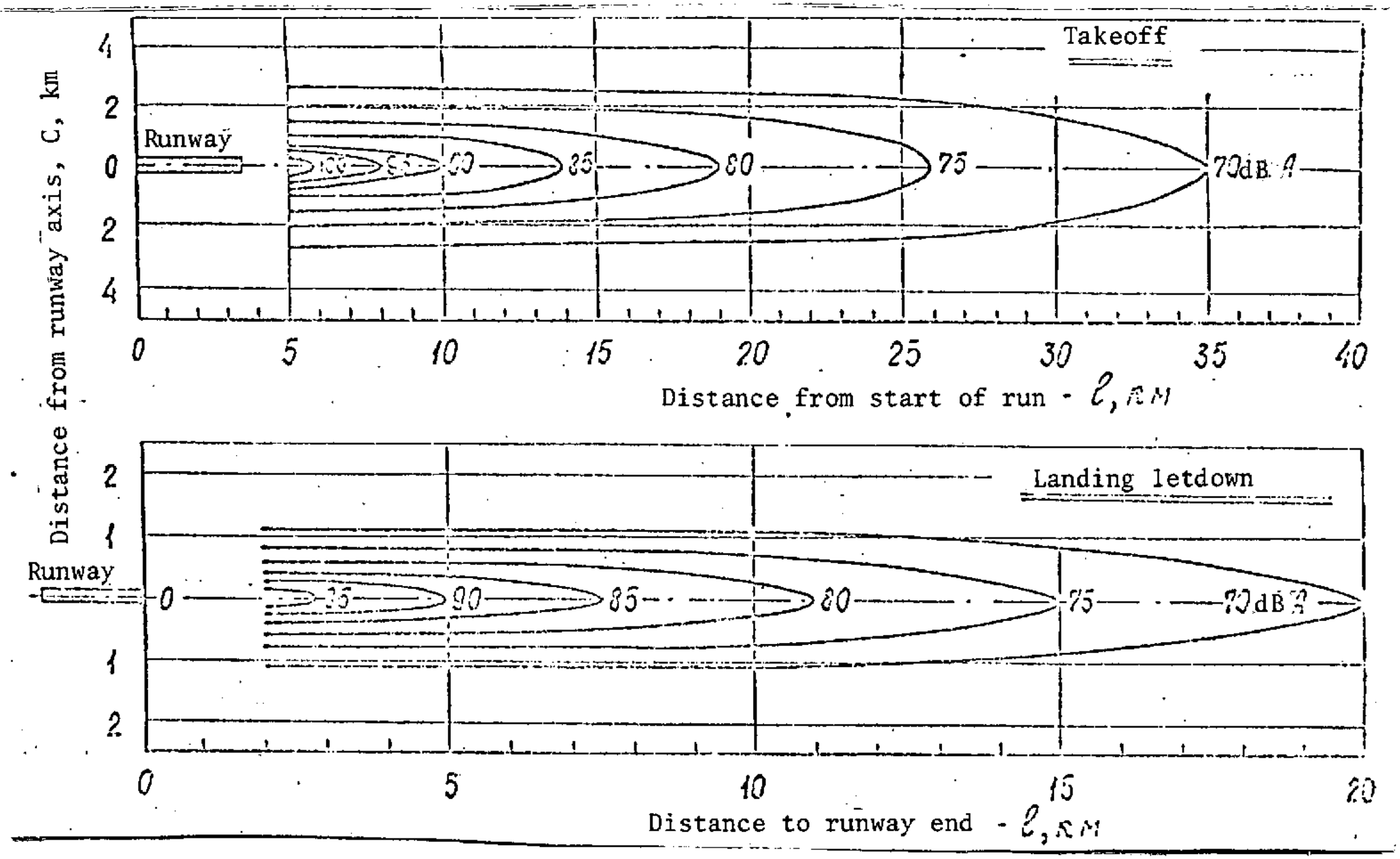

Fig. 9. Typical equal sound level curves L_A (in dB A) for aircraft of second group, adopted as initial ones.

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L_{eq}	N	WECPNL	$\overline{NI}$	B	$\bar{Q}$	NNI	NEF	CNR
92	112	103	90	70	95	70	55	130
82	102	93	80	60	85	60	45	120
72	92	83	70	50	75	50	35	110
62	82	73	60	40	65	40	25	100
52	72	63	50	30	55	30	15	90

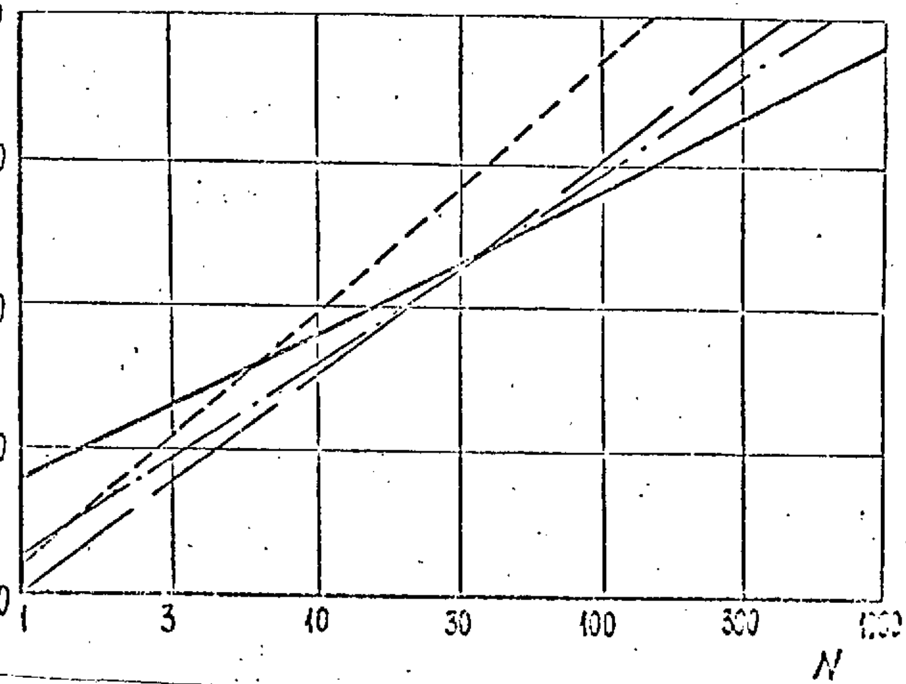

Fig. 10. Comparison of indices of total noise action, used in zoning practice in vicinities of airports, from condition of noise created, in different countries:

— L_{eq}, N, WECPNL, NEF, CNR, $\overline{NI}$; - - - - B; —·—·— NNI; -·-·-·- $\bar{Q}$